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Effects of gamified robot-assisted instruction on medical students' learning outcomes, motivation and fatigue

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Abstract

As digital technologies and artificial intelligence (AI) continue to reshape vocational and professional education, innovative instructional approaches are increasingly needed to enhance learner engagement and facilitate effective knowledge acquisition in clinical training environments. This study developed a gamified AI robot-assisted instruction system that integrates gamification elements with AI-driven robotic instruction to enhance learning motivation and reduce fatigue during clinical training. A single-group design was employed, involving 17 medical students participating in respiratory therapy clinical training. The results showed that learning outcome scores improved following the intervention, although the increase did not reach statistical significance. In contrast, learning motivation increased significantly, while fatigue levels decreased significantly after using the gamified AI robot-assisted instruction system. No significant gender differences were found across the measured variables. These findings suggest that the integration of gamification and AI robot-assisted instruction can create a more engaging and supportive learning environment, helping learners maintain motivation and alleviate psychological burden during clinical training. From a vocational education and training perspective, the study highlights the potential of gamified AI robot-assisted instructional systems to foster learner-centered, interactive, and motivating educational experiences in healthcare training.

Keywords: Artificial intelligence, Fatigue, Gamification, Motivation, Robot.

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Contents

Contribution of this paper to the literature
This study developed the GARI system, integrating interactive robot-assisted instruction with gamification elements for pulmonary rehabilitation training in medical education. Beyond examining learning effectiveness, this study uniquely explored learner fatigue as an additional outcome, providing a broader perspective on the educational impact of AI robot-assisted instruction.

1. Introduction

With the advancement of technology and the changing times, the forms and models of education continue to evolve, and medical education is no exception. Medical education is inherently complex, requiring learners to integrate foundational medical knowledge, relevant clinical contexts, and clinical skills within authentic healthcare environments (Albert et al., 2024). With the growing emphasis on competency-based medical education (CBME), medical students are expected not only to acquire theoretical understanding but also to demonstrate the ability to apply knowledge effectively in real clinical practice (Zhu et al., 2025). However, within traditional instructional models, achieving these educational objectives remains a substantial challenge.

Traditional lecture-based instruction remains widely used in medical education (Ehsanzadeh, Dwyer, Barzegar, & Hamidi, 2026). However, it often encourages passive learning and provides limited opportunities for applying knowledge in authentic clinical contexts. Such approaches may not adequately support the competency-based medical education (CBME) model, which emphasizes critical thinking, clinical decision-making, and practical competence (Boedeker et al., 2025; Liu et al., 2024; Walsh & Maloney, 2018; Zhu et al., 2025). These challenges become even more apparent during clinical training, where educators must simultaneously manage patient care, administrative responsibilities, and student supervision, resulting in fragmented learning opportunities and limited individualized feedback (Mathisen, Bjørk, Heyn, Jacobsen, & Hansen, 2023; Negm et al., 2024).

In recent years, advances in artificial intelligence (AI) and educational robotics technology have opened new possibilities for addressing these challenges. AI technology can deliver personalized learning experiences by providing adaptive feedback and fostering interactive learning environments (Lin & Chen, 2024). Robotics, meanwhile, can precisely execute repetitive tasks and facilitate engaging interactions without workload limitations (Wang, Sang, Huang, Li, & Guo, 2023). Therefore, AI-driven robots hold promise as teaching assistants, helping to alleviate teachers' instructional burdens while supporting students' learning processes (Edwards & Cheok, 2018; Toh, Causo, Tzuo, Chen, & Yeo, 2016; Wang et al., 2023).

Despite the numerous advantages of AI robot-assisted teaching, it is not without its flaws. Past research indicates that AI robots may struggle to convey the emotional connections that are crucial in learning interactions. Furthermore, human-machine interactions may exhibit excessive staring or exaggerated movement patterns. If poorly designed, these can negatively impact learners' attention and overall learning experience (Ao & Yu, 2022). Therefore, addressing the inherent limitations of AI robot-assisted systems has become a critical challenge in advancing their effective application within educational settings.

To address these challenges, integrating gamification strategies into AI-powered robots may prove a promising approach. Gamification strategies involve applying game elements such as points, badges, and leaderboards to non-game educational contexts (Sailer & Homner, 2020). Related research also indicates that gamification strategies enhance learning motivation, learning outcomes, and higher-order thinking skills (Zainuddin, Chu, Shujahat, & Perera, 2020). Within AI robot-assisted teaching environments, gamification features can compensate for potential shortcomings in robotic instruction by enhancing interactivity, sustaining learner engagement, and creating more dynamic learning experiences. However, empirical research on the combined effects of AI robot-assisted teaching and gamification on medical students' learning outcomes remains limited.

To better understand the potential impact of integrating gamification strategies with AI robot-assisted instruction on student learning, this study developed a gamified AI robot-assisted instruction (GARI) system. The GARI system embeds game elements into AI-driven robotic instruction, aiming to enhance learner interaction and sustain engagement throughout the learning process. Therefore, this study aims to investigate the effects of the GARI system on medical students' learning outcomes, learning motivation, and fatigue levels. By examining these dimensions concurrently, the research seeks to comprehensively understand how gamified AI robot-assisted instruction can strengthen medical education and address teaching challenges encountered in contemporary clinical training environments. Specific research questions are as follows:

1. Compared to pre-intervention levels, do medical students using the GARI system demonstrate significantly higher learning outcomes post-intervention?
2. Compared to pre-intervention levels, do medical students using the GARI system exhibit significantly higher learning motivation post-intervention?
3. Compared to pre-intervention levels, do medical students using the GARI system exhibit significantly lower fatigue levels post-intervention?

2. Materials and Methods

2.1. Participants

This study employed a single-group pretest-posttest design to investigate the impact of the GARI system on medical students' learning outcomes. The study participants were respiratory therapy students from universities in various regions of Taiwan who were undergoing clinical training at a medical center in northern Taiwan. Participants were respiratory therapy professionals primarily engaged in clinical internships or training, with 17 learners participating in the study, including 5 males and 12 females.

All participants had completed the prerequisite respiratory therapy curriculum before entering clinical practice and were undertaking pulmonary rehabilitation training during the study period. None had previous experience using the GARI system. The medical course topic covered was "Principles and Fundamentals of Pulmonary Rehabilitation Therapy," emphasizing the integration of clinical practice and professional knowledge. Instruction was delivered by a professional instructor with over ten years of respiratory therapy teaching experience, ensuring the accuracy and consistency of the teaching content.

2.2. Ethical Considerations

This study strictly adheres to the ethical guidelines for educational research involving human subjects. All procedures comply with the provisions of the "Declaration of Helsinki." Prior to data collection, all participants were fully informed about the study's purpose, procedures, and the voluntary nature of participation. All participants signed written informed consent forms. All data from this study were anonymized and coded to ensure privacy. Participants were also informed of their right to withdraw from the study at any time without penalty.

2.3. Gamified AI Robot-Assisted Instruction System

The gamified AI robot-assisted instruction system architecture developed by this research institute comprises three main components: the teacher platform, database, and student platform (Figure 1). Within the teacher platform, educators can create and manage robots through the artificial intelligence robot system and teaching module. This includes pre-setting response content, designing actions, configuring video playback sequences, and arranging instructional sequences. Robots deliver professional knowledge explanations and skill demonstrations according to pre-planned teaching sequences. Students may also engage in self-directed learning at any time during the practical training period.

The database system comprises two sub-databases: the gamified database and the project database, serving as the core bridge linking the teacher platform and student platform. Based on the robot teaching mode set by the teacher, the system retrieves corresponding learning materials from the database for student use on the student platform. During interactions with the robot, students can select relevant learning content according to their individual needs, with the system providing corresponding data to support personalized learning.

Within the student platform, students engage with course activities that integrate gamified elements by interacting with robot-delivered content. Course design incorporates gamification elements such as badges and quiz levels to enhance learning motivation and sustained engagement.

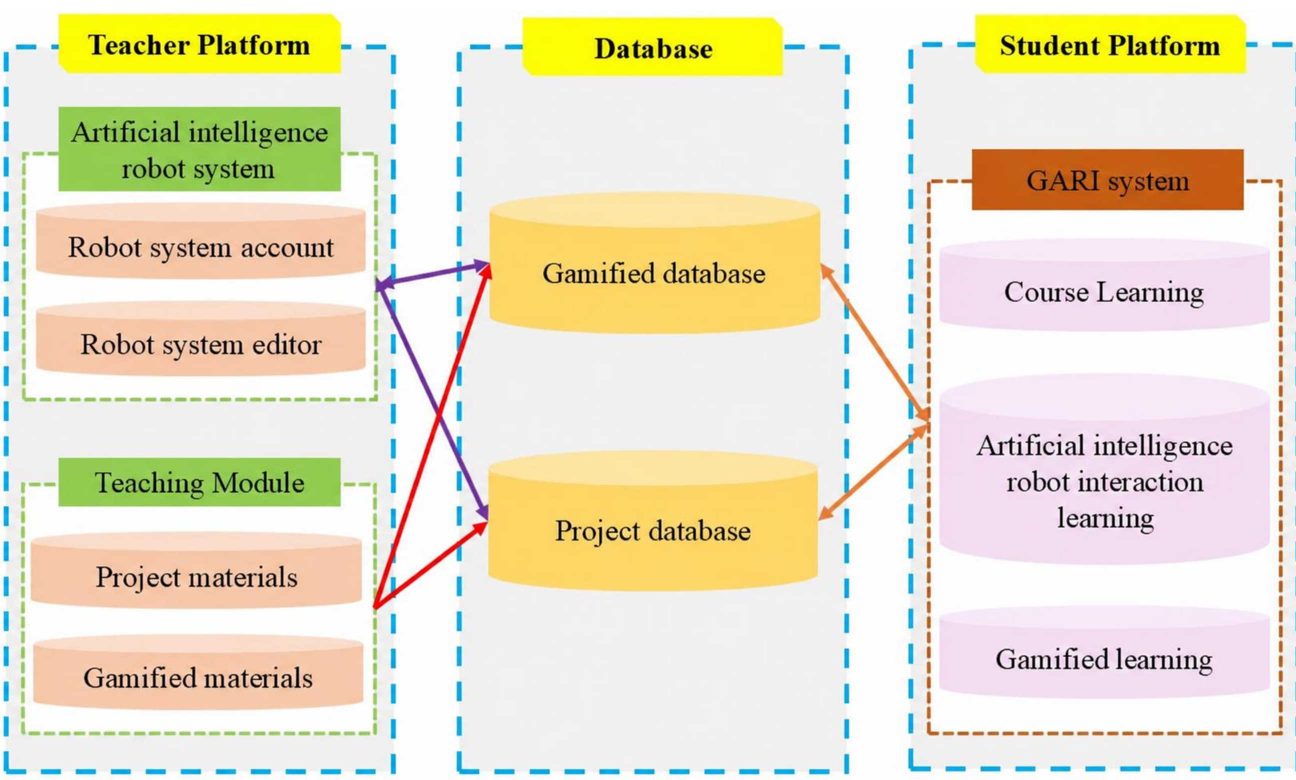

Figure 1. GARI system research framework.

2.4. Experimental Procedure

This study was conducted at a medical center in Taiwan. Prior to the course commencement, the instructor explained the research objectives, procedures, and relevant precautions to the students. The instructor also introduced the GARI system to be integrated into this course and its operational methods, ensuring students fully understood the research content and teaching arrangements.

The clinical practicum session lasted approximately 100 minutes, with the teaching focus on "Principles and Fundamentals of Pulmonary Rehabilitation Therapy". Prior to the formal course commencement, a pretest was administered, comprising an assessment of learning outcomes, a questionnaire on learning motivation, and a visual analog scale for fatigue levels. Following the pretest, the instructional phase commenced, utilizing the GARI system for supplementary instruction and interactive learning activities.

Following the session, students completed a posttest, including the learning outcomes assessment, learning motivation questionnaire, and fatigue visual analog scale, to collect pretest and posttest data for comparative analysis. Upon completion of all assessments, the research will conclude. Figure 2 shows the user interface of the GARI system.

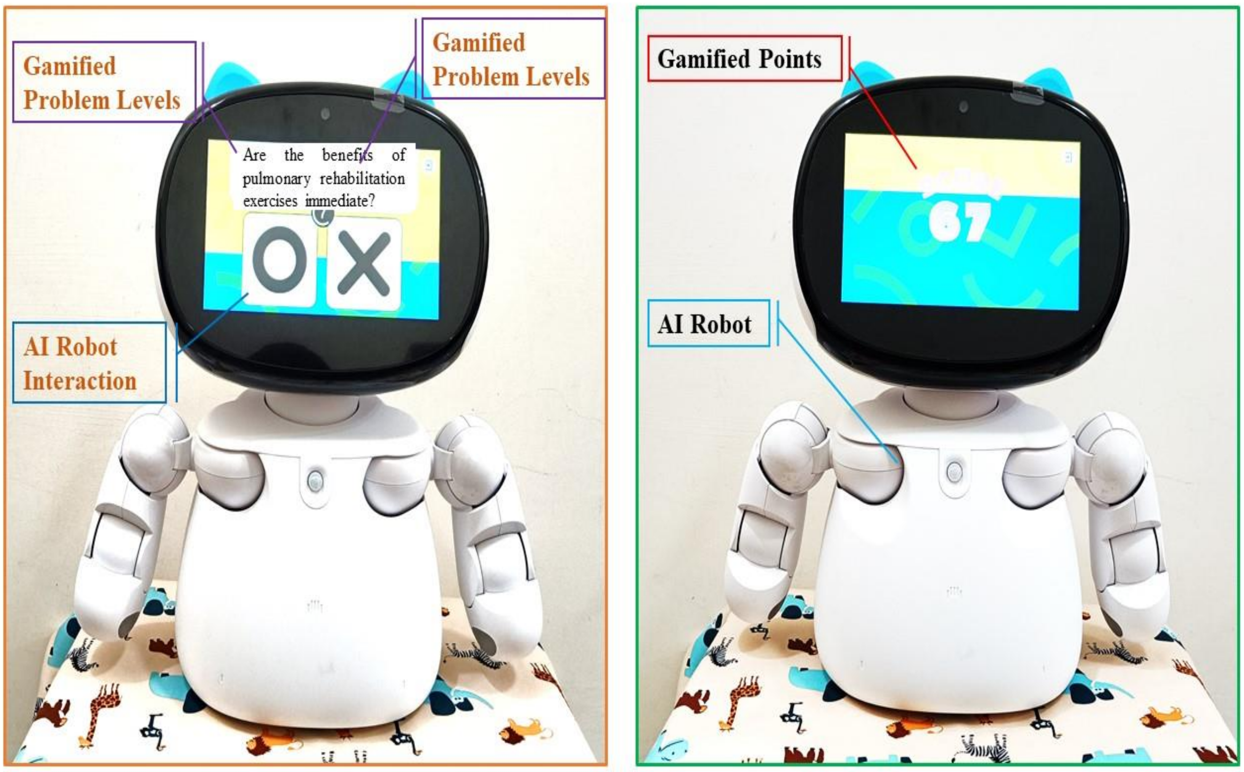

Figure 2. GARI system user interface diagram.

2.5. Instruments

This study employed an assessment test and two scales to evaluate students' learning outcomes, learning motivation, and fatigue levels, respectively. First, the assessment test was developed by a clinical instructor with over ten years of teaching experience. The test comprised 10 multiple-choice questions, each worth 10 points, totaling 100 points. To ensure the professionalism and appropriateness of the test items, the paper underwent review and revision by three medical education experts to align with the teaching focus of this study.

Second, the learning motivation scale was adapted from Hwang, Yang, and Wang (2013). It comprised seven items rated on a five-point Likert scale. The Cronbach's α coefficient was 0.79. An example item is: "I would like to learn more and observe more in the course."

Finally, student fatigue levels were assessed using a visual analog scale (VAS), referencing studies by Koo and Yang (2025) and Delgado et al. (2018). The VAS is a validated subjective measurement tool that quantifies the intensity of an individual's subjective feelings (Bailey, Gabbay, Daoust, & Gravel, 2014; Delgado et al., 2018). Participants marked their fatigue level on a 10-centimeter line using a pen, ranging from "no fatigue" to "extremely fatigued." Compared to the Likert scale, which is an ordinal scale, the VAS offers higher sensitivity and discrimination, allowing for a more nuanced reflection of fatigue changes among students after using the GARI system.

2.6. Statistical Analysis

Data analysis for this study was conducted using SPSS statistical software. First, descriptive statistics were calculated for each research variable to understand the overall distribution and basic trends of the data. Given the single-group design and the small sample size (fewer than 30 students), it was not possible to assume normal distribution of the data. Therefore, the Wilcoxon signed-rank test and Mann-Whitney U test were employed to determine whether there were significant differences in students' pretest and posttest scores for each study variable and whether there were effects across different gender groups. Statistical significance was set at $p < .05$.

3. Result

3.1. Learning Outcomes

The Wilcoxon signed-rank test was conducted to examine students' learning outcomes before and after the implementation of the GARI system. As shown in Table 1, overall learning outcome scores were analyzed, and potential differences across gender were further examined.

The results indicate that the difference in learning outcome scores did not reach statistical significance ($p = 0.124$). Specifically, the median pretest score was 90.00 (interquartile range IQR = 80.00-90.00), while the median posttest score was 90.00 (IQR = 90.00-100.00). Although the median remained unchanged, the interquartile range (IQR) increased in the posttest, indicating an overall upward trend in learning outcomes following the GARI system intervention.

To further explore whether post-intervention learning outcomes differed by gender, the Mann-Whitney U test was applied. Male students ($n = 5$) reported a median score of 90.00 (IQR = 90.00-100.00), while female students ($n = 12$) reported a median score of 90.00 (IQR = 90.00-97.50). The difference between the two groups was not statistically significant ($p = 0.452$). Overall, these findings suggest that although learning outcomes showed an upward trend after the implementation of the GARI system, the improvement did not reach statistical significance, and post-intervention performance did not differ significantly by gender.

Table 1. Comparison of learning outcomes before and after GARI system implementation.

Dimension	Group	N	Percentiles			Z	P
			25th	50th	75th		
Total scores	Pretest Group	17	80.00	90.00	90.00	-1.54	0.124
	Posttest Group	17	90.00	90.00	100.00		
Scores-gender	Male (posttest)	5	90.00	90.00	100.00	-0.75	0.452
	Female (posttest)	12	90.00	90.00	97.50		

3.2. Learning Motivation

The Wilcoxon signed-rank test was also conducted to examine students' learning motivation before and after the implementation of the GARI system. As shown in Table 2, overall learning motivation scores were analyzed, and potential differences across gender were further examined.

The results indicated that students' post-intervention learning motivation scores were significantly higher than their pre-intervention scores ($p = 0.021$). Specifically, the median learning motivation score increased from 29.00 (IQR = 26.50-35.00) in the pretest to 33.00 (IQR = 28.50-35.00) in the posttest. This upward shift in median scores suggests that students' learning motivation has been enhanced after using the GARI system.

To further explore whether post-intervention learning motivation differed by gender, the Mann-Whitney U test was applied. Male students ($n = 5$) reported a median score of 33.00 (IQR = 26.50-35.00), while female students ($n = 12$) reported a median score of 33.50 (IQR = 29.00-35.00). The difference between the two groups was not statistically significant ($p = 0.622$). Overall, these findings indicate that the GARI system was associated with a significant increase in learning motivation, and post-intervention motivation levels did not differ significantly by gender in this study.

Table 2. Comparison of learning motivation before and after GARI system implementation.

Dimension	Group	N	Percentiles			Z	P
			25th	50th	75th		
Total scores	Pretest Group	17	26.50	29.00	35.00	-2.31	0.021*
	Posttest Group	17	28.50	33.00	35.00		
Scores-gender	Male (posttest)	5	26.50	33.00	35.00	-0.49	0.622
	Female (posttest)	12	29.00	33.50	35.00		

Note: *p <0.05.

3.3. Fatigue levels

Students' fatigue levels before and after the instructional intervention were analyzed using the Wilcoxon signed-rank test. Table 3 presents the overall fatigue scores, along with comparisons across gender groups. Fatigue was measured using a 10 cm Visual Analog Scale (VAS). For ease of interpretation and clarity of presentation, all fatigue scores were multiplied by 10 in the analysis. For example, an original rating of 3.7 cm on the VAS is presented as 37 in the reported results.

The results indicated that students' post-intervention fatigue levels were significantly lower than their pre-intervention levels ($p < 0.01$). Specifically, the median fatigue score decreased from 40.00 (IQR = 23.50-58.50) in the pretest to 35.00 (IQR = 17.00-50.50) in the posttest. This downward shift in median values suggests that students experienced a reduction in perceived fatigue following the implementation of the GARI system. Moreover, the posttest interquartile range shifted toward lower values, indicating a general trend of reduced fatigue among students after the instructional session.

Furthermore, the Mann-Whitney U test was conducted to examine differences in post-intervention fatigue levels across gender groups. Male students ($n = 5$) reported a median score of 34.00 (IQR = 9.00-70.50), while female students ($n = 12$) reported a median score of 38.50 (IQR = 21.00-49.75). The difference between the two groups was not statistically significant ($p = 0.833$). Overall, these findings indicate that the GARI system was associated with a significant reduction in fatigue levels, and post-intervention fatigue did not differ significantly by gender in this study.

Table 3. Comparison of fatigue levels before and after GARI system implementation.

Dimension	Group	N	Percentiles			Z	P
			25th	50th	75th		
Total scores	Pretest Group	17	23.50	40.00	58.50	-3.63	<0.01*
	Posttest Group	17	17.00	35.00	50.50		
Scores-gender	Male (posttest)	5	9.00	34.00	70.50	-0.21	0.833
	Female (posttest)	12	21.00	38.50	49.75		

Note: *p <0.05.

4. Discussion

This study introduced the GARI system as an instructional support tool designed to assist medical students in integrating complex medical knowledge and clinical skills during clinical training. By providing structured teaching guidance, standardized technical demonstrations, and a coherent learning experience, the system aimed to enhance learning quality while mitigating diminished motivation and fatigue caused by uneven learning opportunities or fragmented instructional content.

Regarding student academic outcomes, the findings of this study indicate that students' learning outcome scores showed an upward trend following the implementation of the GARI system. However, the improvement did not reach statistical significance. This finding differs from those reported in previous studies. For example, Liang and Hwang (2023) found that robot-assisted instruction significantly reduces students' communication anxiety while enhancing English proficiency. Similarly, Chang, Hwang, and Chen (2023) reported that robot-assisted teaching effectively improves academic performance, learning attitudes, critical thinking awareness, and learning satisfaction.

Several factors may explain the absence of statistically significant differences in the present study. First, the relatively small sample size may have limited the statistical power to detect meaningful differences. Second, participants had already received relevant theoretical instruction and technical skills training before entering hospital-based clinical practice, resulting in relatively high pre-test scores. This may have produced a ceiling effect, thereby limiting the extent of measurable improvement. Furthermore, although previous research has generally demonstrated that robot-assisted instruction positively influences learning outcomes (Chang et al., 2023), most of these studies have been conducted in language learning or general education settings. The instructional objectives and assessment methods in these contexts differ substantially from those in clinical medical education. Unlike general educational settings, clinical medical education requires learners not only to acquire factual knowledge but also to integrate conceptual understanding with procedural skills and clinical reasoning (Linsen, Elshout, Pols, Zwaan, & Mamede, 2018). Consequently, educational interventions that effectively enhance learning outcomes in general educational contexts may not necessarily produce immediate gains in knowledge-based assessments within medical education.

From the perspective of competency-based medical education (CBME), meaningful learning extends beyond improvements in immediate test scores and is better reflected in learners' ability to apply knowledge effectively in authentic clinical settings (Ai Li et al., 2023). Because the present intervention consisted of a single instructional session, the development of clinical competence may require sustained practice and repeated application before measurable improvements can be detected using conventional academic achievement assessments.

On the other hand, this study also examined learning outcomes differences between male and female students, revealing no significant gender-based disparities. This finding diverges from some literature reports. Thiele, Singleton, Pope, and Stanistreet (2016) indicated that male students may exhibit lower academic performance than females. Crowther and Briant (2022) further indicate that findings regarding gender's impact on academic achievement remain inconsistent. Nevertheless, the present study's results suggest that the GARI system yields comparable academic outcomes across different gender groups. This may indicate that the system provides a relatively inclusive and consistent learning support environment, enabling learners of different genders to achieve similar learning outcomes.

Beyond academic achievement, this study also examined students' learning motivation. The results demonstrated that the adoption of the GARI system significantly enhanced students' learning motivation. However, previous research has reported mixed findings regarding the effects of educational robots on learner motivation. Selcuk, Kucuk, and Sisman (2024) suggested that although educational robots positively influence learning outcomes and attitudes, they may also lead to a decline in learning motivation. In contrast, Zhang (2025) reported that robotic applications can effectively enhance students' learning motivation. These inconsistent findings indicate that the motivational effects of educational robots remain inconclusive and warrant further investigation.

One possible explanation for the positive findings of the present study is the integration of gamification elements into the GARI system. Previous studies have consistently shown that gamification can effectively address the common challenge of insufficient learning motivation by increasing learners' engagement and persistence (Lampropoulos & Sidiropoulos, 2024; Zainuddin et al., 2020). Unlike conventional robot-assisted instruction, the GARI system incorporates gamification features, including achievement badges, progressive quiz levels, and immediate interactive feedback, into the learning process. These design elements provide additional motivational support by making learning more interactive, goal-oriented, and rewarding.

The findings can be further interpreted through the lens of Self-Determination Theory (SDT) (Deci & Ryan, 2000), which posits that learners are more likely to maintain intrinsic motivation when their psychological needs for competence, autonomy, and relatedness are fulfilled. In the present study, immediate feedback and achievement badges may have strengthened students' perceptions of competence by providing timely recognition of their progress. At the same time, the interactive learning activities encouraged students to actively participate in the learning process, thereby supporting their sense of autonomy. Furthermore, the collaborative and interactive nature of robot-assisted activities may have fostered relatedness by facilitating communication and interaction among learners and instructors. Collectively, these motivational mechanisms may explain why the GARI system produced significant improvements in learning motivation.

Maintaining learning motivation is particularly important in medical education, where students are required to cope with intensive workloads, prolonged clinical training, and considerable psychological stress. Under these circumstances, instructional approaches that effectively sustain motivation may promote greater engagement and persistence, even when immediate improvements in academic performance are not evident. Therefore, the present findings extend the existing literature by demonstrating that the GARI system can effectively enhance students' motivation rather than diminish it. This suggests that gamification may serve as an important design strategy for maximizing the motivational benefits of educational robots and provides practical guidance for the future development of the GARI system in medical education.

Furthermore, additional analysis revealed no significant differences in learning motivation between male and female students. Although past research has suggested that gender may influence learning motivation (Csizér & Albert, 2024) the present study did not reveal such differences. This finding resonates with the earlier analysis of academic outcomes, indicating that the GARI system may foster a relatively inclusive and equitable learning support environment, enabling students of different genders to achieve similar motivational gains.

In addition to academic performance and learning motivation, this study examined students' fatigue levels. The findings indicated that fatigue decreased significantly following the implementation of the GARI system. This result can be interpreted from the perspective of cognitive load theory proposed by Mayer and Moreno (2003) and Sweller (2024). According to cognitive load theory, information acquired through the senses must be processed within learners' working memory, which has limited capacity and duration. When instructional materials are poorly designed or contain unnecessary information, excessive extraneous cognitive load may be imposed, increasing learners' mental effort, psychological stress, and ultimately learning fatigue. Moreover, because humans process visual and verbal information through two relatively independent channels, each with limited processing capacity, instructional materials should be carefully organized to integrate text, images, and demonstrations in ways that optimize the use of cognitive resources.

Previous studies in gamified learning environments have similarly demonstrated that well-designed interactive elements can sustain learners' attention and engagement without imposing excessive cognitive demands (Gallen, Schachtner, Anguera-Singla, Anguera, & Gazzaley, 2023; Lin, 2023). The present findings are consistent with this perspective. The GARI system may have reduced unnecessary extraneous cognitive load through its structured instructional sequence, standardized teaching procedures, clear learning guidance, and consistent technical demonstrations accompanied by immediate feedback. These instructional features likely enabled students to allocate more cognitive resources to essential learning tasks rather than to processing irrelevant or disorganized information, thereby reducing learning fatigue.

Importantly, the reduction in fatigue should not be attributed solely to the presence of the educational robot. Rather, it is more likely the result of the combined effects of multiple instructional design features embedded within the GARI system, including structured learning sequences and gamified interactions. Together, these elements may minimize unnecessary cognitive processing while supporting more efficient allocation of mental resources to core learning activities. This interpretation is also consistent with cognitive load theory, which emphasizes that effective instructional design reduces extraneous cognitive load, thereby improving learning efficiency.

The observed reduction in fatigue has important implications for clinical medical education. Clinical training requires students to assimilate substantial amounts of information while simultaneously adapting to unfamiliar healthcare environments, managing complex procedures, and coping with considerable psychological demands (Negm et al., 2024). Under these conditions, instructional approaches that reduce unnecessary cognitive burden may help learners maintain concentration, sustain engagement, and improve learning efficiency throughout clinical practice. Therefore, beyond enhancing learning motivation, the GARI system may represent a promising instructional approach for supporting students' cognitive well-being in demanding clinical education settings.

Furthermore, the comparison results between different gender groups did not reveal significant differences, indicating that both male and female students experienced similar reductions in fatigue after using the GARI system. This finding further suggests that the GARI system may create a relatively equitable and supportive learning environment, benefiting learners of all genders.

Although the findings of this study are instructive, its limitations warrant careful consideration. First, this study employed a single-group pre-post design without a control group. While significant improvements were observed following the GARI system intervention, these may have been influenced by external environmental factors or ceiling effects. Therefore, inferences drawn from the results should be interpreted with caution. Second, the relatively small sample size and the fact that all participants were drawn from a single medical center may limit the generalizability of the findings. In addition, the gender analyses were based on a small and unequal sample (five male and twelve female participants), resulting in limited statistical power. Therefore, the non-significant gender differences observed in this study should be interpreted with caution and require confirmation in future studies with larger and more balanced samples. Finally, this study primarily focused on short-term outcomes following the intervention. Whether these benefits can be sustained long-term remains to be verified through subsequent follow-up studies.

5. Conclusions and Future Research Suggestions

This study introduced the GARI system as an innovative AI robot-assisted teaching method. Findings indicate that structured guidance, standardized demonstrations, and feedback effectively bridge foundational knowledge with practical clinical applications. Although the improvement in learning outcomes following the intervention was not statistically significant, overall, the GARI system had a positive impact on students' learning outcomes, motivation, and fatigue levels.

However, given the limitations of this study, several areas warrant further exploration. For instance, more rigorous experimental designs, a more diverse sample population, and the incorporation of qualitative analysis are needed to enrich and validate these findings. Additionally, long-term follow-up studies could be conducted to assess the sustainability and broader applicability of the GARI system within medical education.

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